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(PROFESSIONAL PAPER.)

FIELD STUDIES OF THE CROWN-GALL OF SUGAR BEETS.

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KINDS OF BEET GALLS.

There are at least two distinct but clearly related kinds of growths occurring upon sugar beets which may be considered under the name of galls. These have been designated as "tumors" and "tuberculosis" in Bulletin No. 213 of the Bureau of Plant Industry.[1] While these two kinds of outgrowths are similar in external appearance, especially in their early stages of development, their internal appearance and their subsequent behavior serve to distinguish the tumor from tuberculosis. Internally, the outgrowths known as tuberculosis of the beet show small, brownish, water-soaked areas, as mentioned on page 194 of the bulletin cited, while the tumor is free from these discolored areas. Externally, both kinds of galls are usually smooth at first, but the tuberculosis galls eventually become decidedly rough, cracked, and very dark, and finally decay. This decay of the galls often causes the beet itself to rot, thereby entailing more or less loss on the grower, according to the prevalence of the disease. On the other hand, the tumor remains comparatively smooth, seldom cracks, does not usually decay, and frequently retains its firmness until the beets are harvested. The quality of the galls and their effect upon the beets from which they arise, as given in this paper, relate for the most part to the tumor variety.

DISTRIBUTION OF BEET GALLS.

The abnormal outgrowths known in this country as crown galls have been observed upon beet plants from time to time for more than 50 years. Indeed, as early as 1839 attention was called to these

[1] Smith, Erwin F., Brown, Nellie A., and Townsend, C. O. Crown-gall of plants: Its cause and remedy. U. S. Dept. Agr., Bur. Plant Indus. Bul. 213, p. 105, 194. 1911.

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peculiar growths upon beet roots, which were spoken of at that time as warts. In 1859 some of these galls were described as larger than the beet roots themselves and were looked upon as curiosities and monstrosities. It appears from a study of the literature upon the subject and from observations in the field from year to year that this disease of the sugar beet has increased rapidly in recent years and that it is still on the increase. Its presence has been recorded in many of the beet-growing countries of Europe, and in our own country it has been found on the sugar beet from Virginia to California. (Fig. 1.) In many localities where only a small number of cases were observed a few years ago, there are now hundreds and sometimes thousands of galled beets each year, especially if beets have been followed by beets for several years in the same field. On the beet itself the galls may appear at any point from the top of the crown to the extreme tip of the root. However, by far the largest number of galls are to be found at or near the surface of the ground, and for this reason these growths have been termed crown galls.

FIG. 1.—Map of the United States, the shaded portions showing the areas where sugar-beet galls have been observed.

APPEARANCE OF BEET GALLS.

The outgrowths, or galls, on the beet do not usually appear until the beets are from one-fourth to one-half grown; that is, until midsummer. From that time on, they may appear at any time until the beets are harvested. Consequently, we may find at harvest time galls in all stages of development, from tiny protuberances that have just begun to grow to what might be called the full-grown gall, several inches in diameter, as shown in Plate I, *A* to *K*. Frequently, these galls push out from the surface of the beet without any distinct line of demarcation between the gall and the beet proper, as seen in Plate II, *B*. In other cases the outgrowths are attached to the beet by very slender necks or threads, and between these extremes may be seen the full range of variation in relative size of the connecting tissue. Whether large or small, the connections are short, so that the gall almost invariably lies close to the beet from which it springs. Sometimes but a single gall is produced on one beet, as shown in Plate I, *F* to *K*, while in other instances several or many galls may develop on the same beet, as illustrated in Plate II, *A*, *B*, *C*, and *F*. In the latter case the galls may be distinct and separate (Pl. II, *A*) or they may occur in groups (Pl. II, *B*). It is not uncommon for the entire crown of the beet to be covered with a mass of galls (Pl. I, *E*).

Usually the galls with slender attachments occur singly, although there may be several on the same beet, while the galls occurring in groups usually have broad bases without any distinct line between the gall and the beet. In the early stages of development—that is, when the galls are young—their surfaces are bright, resembling the surface of the beet proper and indicating active growth; but as the galls grow older they become darker, especially if they are above the surface of the ground. In this way their relative ages may be easily determined. When galls have begun to form they usually increase in size most rapidly on those beets that are making the most rapid growth.

CAUSE OF BEET GALLS.

The primary cause of the formation of crown galls on the sugar beet and many other plants was for a long time in doubt. Few plant diseases have given rise to more extended investigations than has the so-called crown-gall. Different investigators have assigned the origin of these abnormal growths to a great variety of causes, ranging from slime molds to mechanical injuries. However, the investigations set forth in Bulletins Nos. 213 and 255 of the Bureau of Plant Industry[1] prove conclusively that a bacterium or several closely related bacteria are responsible for the origin and development of these outgrowths belonging to the class of so-called crown galls. The organism producing "tumors" is known as *Bacterium tumefaciens* (Smith and Townsend) and the one producing "tuberculosis" is designated as *B. beticolum* (Smith).[2]

The most extensive work on mechanical injuries as the cause of gall formations on sugar beets has been carried on by Spisar.[3] There seems to be no proof, however, that the organism which is capable of producing galls on sugar beets was not present in the fields in which Spisar carried on his experiments. It is apparent that a mechanical injury offers a favorable place for the organism to enter the plant, yet the indications are that gall formations will not result from mechanical injuries unless the gall-producing organism is present. In the field studies on the crown-gall of beets carried on by the writer for several years, it has been frequently noted that when galls begin to appear on the beets in a given field they are at first few in number, increasing from year to year if beets continue to be grown in that field. It has also been noticed that if badly infested fields are followed one or two years with a grain crop and then returned to

[1] Smith, Erwin F., Brown, Nellie A., and Townsend, C. O., op. cit.

Smith, Erwin F., Brown, Nellie A., and McCulloch, Lucia. The structure and development of crown-gall: A plant cancer. U. S. Dept. Agr., Bur. Plant Indus. Bul. 255, 60 p., 2 fig., 109 pl. 1912.

[2] These organisms are described in Bureau of Plant Industry Bulletin 213, which may be obtained from the Superintendent of Documents, Government Printing Office, for 40 cents, 10 cents additional being required for postage to foreign countries.

[3] Spisar, Karl. Über die Bildung des Zuckerrüben-Kropfes. *In* Ztschr. Zuckerindus. Böhmen, Jahrg. 36, Heft 1, p. 1–17, fig. 1–6; Heft 2, p. 57–72, fig. 7–11. 1911.

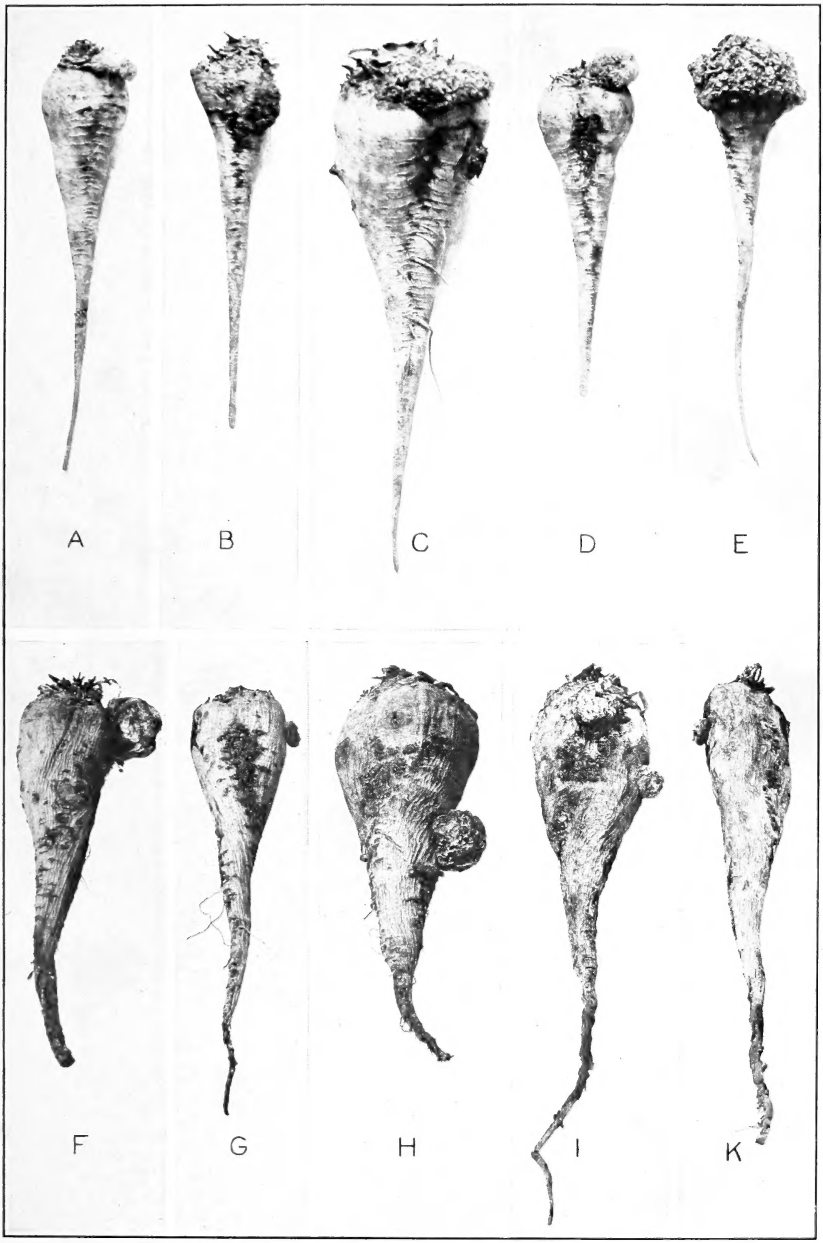
beets, the galls are greatly reduced in number after one year in grain and practically eliminated after two years. It is true that when galls are present in a field of beets they are frequently more numerous near the ends of the rows, where the greatest amount of mechanical injury is produced by the horses and cultivator in turning. (See Pl. II, *E* and *F*.) However, adjacent fields and even parts of the same field not previously in beets, but in which the beets at the time of the observation were subjected to the same mechanical injuries, were free from galls (Pl. II, *D*), regardless of the fact that the soil, climatic conditions, and cultural methods were the same. While certain plant galls and callus formations may be produced by other agencies, all extensive laboratory, greenhouse, and field studies on the crown-gall of sugar beets lead to the conclusion that in this country the true crown-gall formations of this class are produced by bacteria.

QUALITY OF BEET GALLS.

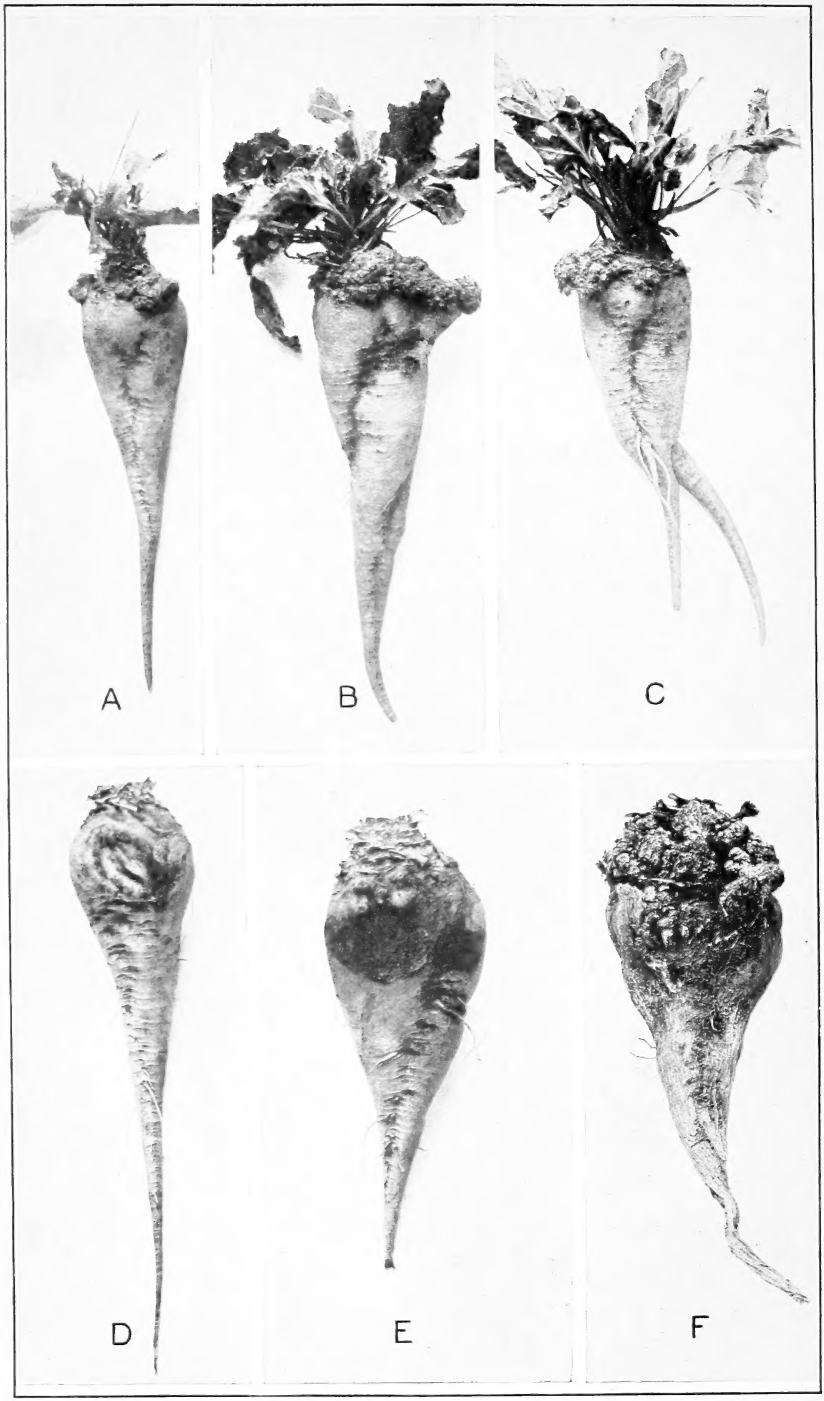
In topping beets from which sugar is to be obtained, it is customary to cut off the crowns at the line of the lowest leaf scar. The reason for rejecting the crowns, as generally known, depends on the fact that as a rule they contain a high percentage of salts, which tend to prevent the sugar from crystallizing in the mill. In the process of topping the beets it frequently happens that a part or all of the galls that occur on the beets are so located that they are left on the root (Pl. I, *F* to *K*) and are, therefore, put through the mill. In order to find out whether or not the galls might affect injuriously the juices in the mill, a series of tests was made to determine the quality of the galls as compared with the beet crowns and roots. The results of these tests are given in Table I, the analytical work for this and the succeeding table having been performed at the Garden City, Kans., laboratory by Mr. C. A. Hauser.

TABLE I.—*Sugar tests of beets affected with crown-gall.*

Part of beet tested.	Average weight of part tested.	Solids in juice.	Sugar in juice.	Coefficient of purity.	Sugar in part tested.
Experiment 1:	*Ounces.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Galls	3.2	15.32	9.00	58.74	5.00
Crowns	13.6	14.10	10.10	71.63	8.90
Roots	24.0	14.30	11.00	76.92	10.00
Experiment 2:					
Galls	4.0	15.60	8.10	51.92	4.60
Crowns	11.2	12.70	8.20	64.56	7.50
Roots	25.6	14.10	11.00	78.01	10.20
Experiment 3:					
Galls	3.2	16.00	9.20	57.50	7.10
Crowns	13.6	15.40	10.80	70.20	10.20
Roots	29.8	15.00	11.40	76.00	10.70
Experiment 4:					
Galls	5.6	15.30	7.80	50.98	7.00
Crowns	18.4	13.10	9.00	68.70	8.40
Roots	32.8	13.10	10.10	77.09	10.00
Experiment 5:					
Galls	8.0	16.60	9.10	54.81	5.90
Crowns	18.4	14.60	9.90	67.80	8.50
Roots	44.8	14.10	10.50	74.46	9.00



GALLED SUGAR BEETS, SHOWING THE VARIOUS LOCATIONS OF THE GALLS.



SUGAR BEETS, SHOWING GALLS APPEARING SINGLY AND IN GROUPS (A, B AND C) AND THE RELATION OF INJURY TO GALL FORMATION (D, E, AND F).

TABLE I.—*Sugar tests of beets affected with crown-gall*—Continued.

Part of beet tested.	Average weight of part tested.	Solids in juice.	Sugar in juice.	Coefficient of purity.	Sugar in part tested.
Experiment 6:	*Ounces.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Galls	3.2	17.46	11.10	63.57	10.40
Crowns	8.0	18.40	14.40	78.26	12.50
Roots	30.4	19.56	16.80	85.88	14.00
Experiment 7:					
Galls	2.4	17.20	9.10	52.90	8.30
Crowns	7.2	18.76	15.40	82.08	13.10
Roots	22.4	17.76	14.80	83.33	13.50
Averages:					
Galls	4.23	16.21	9.05	55.60	6.90
Crowns	12.91	15.29	11.11	72.03	9.87
Roots	29.97	15.41	12.23	78.81	11.06

In preparing the material for the analyses which form the basis of this table badly galled beets were taken in groups of five in order to get a sufficient quantity of juice from the galls to make purity as well as sugar determinations of the galls themselves. After removing the leaves only, the beets were thoroughly washed and weighed. The galls were then carefully removed and the beets again weighed. The crowns were then removed and the roots weighed. The three lots of material from each group of five beets were prepared and put through the test for sugar and purity as quickly as possible after the beets were taken from the ground. A study of Table I shows that the galls are decidedly lower in both sugar and purity than even the crowns. It is evident, therefore, that any considerable number of galls on the beet roots would be decidedly injurious to the sugar recovery in the mill, since the large amount of salts in the galls, as indicated by the low purity coefficient, would keep approximately one and a half times as much sugar from crystallizing. Hence, it would be advisable to remove any galls that are attached to the beets below the crowns at the time of topping the beets.

It might not be out of place in this connection to call attention to the high quality of the crowns in some cases, as shown especially in experiment 7. It is possible that the salts were taken up by the galls to the improvement of the crowns to some extent. On the other hand, it is possible that the quality of the crowns might be greatly improved by proper selection, so that the matter of crown tare would not be such an important factor in handling factory beets as it is at present.

EFFECTS OF GALLS UPON QUALITY AND SIZE OF ROOTS.

In an effort to get some definite information regarding the effect of the galls upon the quality of the roots to which they are attached, a series of comparative tests was made between galled beets and beets free from galls. In selecting the beets for these tests a badly galled

beet was taken as soon as it was loosened by means of the plow at harvest time, and for comparison another beet was chosen, free from galls, but as nearly the same size and shape as could be found growing in the same row, close to the galled beet. After selecting in the manner described the 26 pairs of beets which form the basis of Table II, each beet was topped, washed, and the galls carefully removed from the galled beet of each pair. The individual roots were then tested for sugar and purity, with the results shown in Table II.

TABLE II.—*Comparison in sugar content and purity of galled beets with beets not so affected.*

Condition of beets.	Solids in juice.	Sugar in juice.	Coefficient of purity.	Sugar in the beet.
Test No. 1:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Galled	13.70	10.00	72.99	8.30
No galls	18.10	13.80	76.24	12.20
Test No. 2:				
Galled	13.90	10.50	75.35	9.20
No galls	18.00	13.80	76.66	12.80
Test No. 3:				
Galled	17.60	14.50	82.38	11.70
No galls	21.92	18.60	84.85	16.80
Test No. 4:				
Galled	15.77	13.20	83.70	11.20
No galls	21.50	18.70	86.97	16.80
Test No. 5:				
Galled	15.70	12.80	81.52	10.90
No galls	20.20	17.10	84.65	16.80
Test No. 6:				
Galled	16.30	13.10	80.36	11.40
No galls	20.20	17.10	84.65	16.80
Test No. 7:				
Galled	16.47	13.20	80.14	11.20
No galls	20.17	16.40	81.30	15.10
Test No. 8:				
Galled	10.85	9.30	85.71	8.50
No galls	18.90	15.60	82.53	14.00
Test No. 9:				
Galled	15.27	12.40	81.20	11.70
No galls	16.77	13.90	82.83	13.40
Test No. 10:				
Galled	16.40	13.80	84.14	13.10
No galls	15.77	12.80	81.16	12.00
Test No. 11:				
Galled	16.23	12.10	74.55	11.20
No galls	22.56	19.10	84.66	18.50
Test No. 12:				
Galled	18.77	14.00	74.58	11.50
No galls	22.99	18.20	79.13	17.30
Test No. 13:				
Galled	18.20	14.80	81.31	14.10
No galls	18.77	15.00	79.91	13.80
Test No. 14:				
Galled	17.60	15.40	87.50	14.30
No galls	19.40	16.40	84.53	16.00
Test No. 15:				
Galled	18.07	14.50	80.24	13.10
No galls	19.50	16.10	82.56	16.00
Test No. 16:				
Galled	18.27	15.10	82.64	14.10
No galls	20.50	16.00	78.04	15.70
Test No. 17:				
Galled	18.60	14.80	79.56	13.10
No galls	22.43	19.00	84.70	18.20
Test No. 18:				
Galled	21.00	17.00	81.42	15.40
No galls	21.30	17.90	84.03	16.80
Test No. 19:				
Galled	22.40	18.90	84.37	17.20
No galls	23.00	19.20	83.47	17.20
Test No. 20:				
Galled	16.92	14.00	82.74	14.00
No galls	14.40	12.10	84.02	11.80

TABLE II.—*Comparison in sugar content and purity of galled beets with beets not so affected*—Continued.

Condition of beets.	Solids in juice.	Sugar in juice.	Coefficient of purity.	Sugar in the beet.
Test No. 21:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Galled	18.80	16.50	87.76	16.30
No galls	18.32	15.90	86.79	15.20
Test No. 22:				
Galled	16.42	13.30	80.99	12.60
No galls	16.62	13.90	82.39	12.40
Test No. 23:				
Galled	16.50	13.40	81.21	11.70
No galls	17.72	14.60	82.39	13.90
Test No. 24:				
Galled	18.70	15.30	81.81	14.20
No galls	22.12	18.00	81.37	16.70
Test No. 25:				
Galled	14.87	13.00	87.42	12.20
No galls	22.97	19.30	84.02	17.60
Test No. 26:				
Galled	19.07	15.20	79.70	13.90
No galls	16.07	13.60	84.62	12.50
Average:				
Galled	17.01	13.85	81.35	12.54
No galls	19.66	16.21	82.15	15.18

A study of Table II indicates that gall formations on sugar beets have a tendency to reduce both the sugar content and the purity of the roots. The effect upon the sugar content seems to be more marked than upon the purity. Everyone who has studied the individuality of the sugar beet knows that there is a difference in the sugar content and purity of healthy beets growing side by side in the same row. It is not surprising, therefore, that an occasional pair shows qualities favorable to the galled beets, as in tests Nos. 10 and 21 of Table II. It is safe to say, however, that in the great majority of cases the formation of galls upon the roots of sugar beets has a decidedly injurious effect upon either the purity or the sugar content or upon both these factors of quality in the beet root.

It seems to be practically impossible to obtain any accurate data regarding the effect of galls upon the size of the roots affected. We find the largest as well as the smallest beets more or less seriously infested with galls, as shown in Plate I, *A* to *E*, and it is impossible to know whether the galled beets would have been larger or smaller if they had been free from galls. In some infested areas the larger beets are more generally galled, while in other infested areas the smaller beets are the ones most generally affected; and since the individuality of the beet embraces the size and shape, as well as the quality of the roots, a satisfactory comparison of the weights of the galled and not galled beets has not been practicable in any of the areas that have come under the observation of the writer. So far as one can judge from general field observations, however, the galls do not seem to have any marked effect upon the size of the beets. Consequently the tonnage or yield of beets per acre does not seem to be appreciably affected by the disease except in those cases in which the galls cause the beet roots to decay.

CONTROL OF BEET GALLS.

From our present knowledge of the cause of the crown-gall of beets, combined with the field observations already made upon this disease, its elimination or control becomes comparatively simple. As already suggested, a beet field badly infested with the crown-gall organism may be freed from the pest by growing some other crop in that field for two or more years before returning to sugar beets. It is necessary only that the rotation crops other than beets shall be such as are not readily attacked by the crown-gall organism. In Bulletin No. 213 of the Bureau of Plant Industry, already mentioned, it is pointed out that the crown-gall organism will attack a large number of plants in a great variety of families, but there are plants which are attacked with difficulty, if at all, by this organism. In the test mentioned in this bulletin the crop grown was oats, but it is safe to say that any of the small grains, corn, kafir, milo, or sorghum would do well. If only those crops are grown upon which the organism can not feed and thrive, it must eventually die out and the field be left free from the pest. The elimination of crown-gall is, therefore, a simple matter of wise crop rotation, which as a matter of good farming should be practiced by every farmer regardless of the presence of crown-gall.

SUMMARY.

(1) There are at least two distinct types of sugar-beet galls.

(2) The crown-gall of sugar beets is caused by a bacterium or a number of closely related bacteria.

(3) Sugar-beet galls appear to have an injurious effect upon the quality of the roots.

(4) The galls themselves are low in purity and therefore detrimental in the milling processes.

(5) Sugar-beet galls sometimes cause the beet roots to decay, but, so far as general field observations can determine, they do not appear otherwise to affect the tonnage.

(6) This disease may be held in check by a proper system of crop rotation with grain-producing plants.

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